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AN EVALUATION OF THE F/FB/EF-111 CREW/VOICE MESSAGE SYSTEM INTERFACE

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Crew Station Design Facility
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In support of the F/FB/EF-111 Digital Flight Control System Program Office, subjective and performance data were collected in order to provide the government and contractor engineers with information needed in the design of a Voice Message Unit (VMU) interface for the F/FB/EF-111 aircraft. The VMU, one of the new safety of flight systems, is being included as part of the Digital Flight Control Computer. The VMU will be used as a means for alerting crew members to flight critical conditions. The evaluation was comprised of two phases. During the first phase, questionnaire data were collected from a sample of 119 operational F/FB/EF-111 crew members. The second phase of the evaluation involved the mechanization of the VMU interface in an FB-111 simulator, located at the Crew Station Design Facility, for pilots' on-hand experience with the content of the voice messages and the mechanization aspects of the interface. Objective and subjective data were collected throughout the simulated missions. The results of the two-phase evaluation identified the following F/FB/EF-111 specific issues: (1) The most appropriate voice messages were

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identified to be Pullup (GCAS warning), TF-Low (Set Clearance Plane [SCP] violation warning), Alpha-Side-Slip (AOA-SS caution), and Autopilot Failed (autopiot failure caution); (2) The prioritization scheme should have the warnings and cautions in the following order: GCAS warning, followed by an SCP violation warning, an AOA-SS caution, and finally an autopilot failure caution; finally, (3) Warning messages should be presented continuously until a manual response is performed, while caution messages should only be repeated two or three times. A portion of the results were not necessarily confined to the F/FB/EF-111 cockpit and may therefore be used to generalize to other cockpits. The following is a description of the more generalizable results: (1) A voice warning mode is preferred over either tone or light alone; (2) a tone stall warning mode was most often selected by the subjects over voice stall warning mode; (3) in case a voice stall warning mode is to be considered, then most appropriate message would be "STALL"; and (4) when presenting a voice message, more pilots prefer to hear the voice of a female as opposed to a male speaker.

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INTRODUCTION

An effort to upgrade the F/FB/EF-111 aircraft, through the addition of a Digital Flight Control Computer (DFCC), is currently underway. One of the new safety of flight inclusions into the Digital Flight Control System (DFCS) is a Voice Message Unit (VMU). The VMU will be used as a means for alerting crew members to flight critical conditions. The following are four alerts, included in the F-111 VMU, which are of interest to this study: (1) A ground collision warning (which uses a Ground Collision Avoidance System (GCAS) algorithm); (2) a Set Clearance Plane (SCP) violation warning; (3) an Angle Of Attack/Side slip (AOA/SS) caution indicating performance degradation in Angle Of Attack limiter and adverse yaw compensation; (4) and a caution informing the crew of an autopilot malfunction.

The Crew Station Design Facility was tasked by the F-111 System Program Office (SPO) to evaluate the design of the Crew/VMU interface proposed by General Dynamics.

Current military standards do not provide specific directions in the design of crew members/VMU interfaces. While MIL-STD-1472C (HUMAN ENGINEERING DESIGN CRITERIA FOR MILITARY SYSTEMS, EQUIPMENT AND FACILITIES) contains a section specifying the design of a general purpose audio display interface, the information is incomplete for applications related to aircraft cockpit environments. In turn, MIL-STD-1472C section 5.3.1.6 references MIL-STD-411D (AIRCREW STATION WARNING SIGNALS) as the appropriate document for designing audio signals for aircrew stations. The following is the verbal auditory warning signals excerpt from MIL-STD-411D:

5.2.5 Verbal auditory warning signals - Verbal warning signals shall be audible signals in verbal form indicating the existence of a hazardous or imminent catastrophic condition requiring immediate action and shall only be used to complement red warning or other critical visual signals. The verbal warning signals shall be presented at levels which will insure operator reception under noise conditions in the specific aircraft. There shall be provision for overriding and reseting the signals. The signal, when activated, shall always start at the beginning of the message and shall continue to be presented until either:

(a) The causative condition is corrected.
(b) A warning of higher priority is presented.
(c) The signal is silenced by manual actuation of the override switch.

The structure for verbal warning shall be:

(d) General heading - i.e., the system or service is involved.
(e) Specific subsystem or location
(f) Nature of emergency

Example:	ENGINE	No. 1	HOT
	(d)	(e)	(f)

Several topics remain undefined. These include such items as the format of caution verbal messages; inter-message time; prioritization; distinction between verbal caution and warning messages; etc..

The following write-up describes a two phase study which

attempts to resolve some general issues concerning voice message units, as well as issues specific to the selection of the F/FB/EF-111 voice messages. Phase I of this study involved the collection of questionnaire data from operational F/FB/EF-111 crew members. The questionnaire results were used to influence the design of a Phase II study, in which pilots were given the opportunity to fly a VMU mechanized FB-111 simulator and evaluate its overall adequacy.

PHASE I
VOICE MESSAGE SURVEY

The intent of the questionnaire survey was to collect F/FB/EF-111 crew members' preference data related to specific F/FB/EF-111 VMU design issues. In order to generalize, the survey also collected preference data on several topics related to generic voice warnings and cautions.

Method

Subjects

The CSDF distributed 150 surveys to the user population (75 TAC and 75 SAC), of which 120 were returned (a response rate of 80 percent). The data from one of the 120 subjects, who had previously experienced voice messages in a cockpit environment, were deleted from the analysis to avoid biasing the results. Flying experience ranged from 550 to 4750, with a mean of 2104 F/FB/EF-111 flying hours.

Apparatus

The questionnaire, titled "F/FB/EF-111 Digital Flight Control System -- Voice Warning Survey," was comprised of three main data collection sections. A copy of the survey is shown in Appendix A. The first section elicited subjects' personal information used to establish the sample pool. The second main section of the survey collected data relevant to the four caution and warning messages which were of interest to the proposed F/FB/EF-111 VMU: (1) GCAS warning; (2) SCP violation warning; (3) AOA/SS caution; and (4) autopilot malfunction caution. Questions asked were related to the appropriateness of each message, and the frequency

of repetition of that message. The third section of the questionnaire asked the subjects about general voice related topics. The specific questions elicited data related to the prioritization of the F-111 messages, preference of voice gender, mode of presentation, and proposed stall messages. The subjects were also asked to write any comments they perceived as relevant to the topics being discussed.

Procedure

The System Program Office (SPO), simultaneously and in equal numbers, mailed 150 copies of the survey to the following F/FB/EF-111 SAC and TAC Air Force communities: Cannon AFB; Plattsburg AFB; Langley AFB; and Mountain Home AFB. Completed copies were returned to the SPO within six weeks of the mailing date. Upon the return of the copies, a data base was created to hold all the information collected from the crew members for subsequent data reduction and statistical analysis.

Design

The first Phase of the experiment was designed to compare frequency data as a function of the number of options provided for selection. One-way Chi Square (X^2) analyses were computed for each of the questions asked. Results with confidence probability levels of .95 were considered to be significant.

Survey Results and Discussion

Individual one-way Chi Square tests were performed to analyze the subjective reports for each of the items covered in the voice survey. For each question, response frequency as a function of the available, or generated options are presented in a figure. Related F/FB/EF-111 VMU comments, provided by the subjects, are listed in Appendix B.

VMU Voice Messages

GCAS Warning. The frequency data for message selection and number of presentation are shown in Figures 1a and 1b. The statistically significant X^2 analysis for the message selection ($X^2 = 111$, $p<.05$) implies that most crew members preferred the message PULL-UP (with 65 out of 119 votes), as a warning for a GCAS warning, over the other four messages (GROUND COLLISION; RECOVER; ALTITUDE; and LOW ALTITUDE). None of the other messages were comparable to PULL-UP. ALTITUDE came in second with only 19 votes.

An inspection of Figure 1b suggests that most crew members preferred that the GCAS warning be presented until some type of a manual response is performed by the crew. Statistically significant Chi Square results were found in the analysis of the frequency data, $X^2 = 48$, $p<.05$.

SCP Violation Warning. The Chi Square analysis on the SCP violation voice message data (shown in Figure 2a) resulted in a statistically significant difference between the five available options (ALTITUDE; A-LOW; PULL-UP; TF-LOW; and LOW ALTITUDE), with TF-LOW accumulating the highest frequency

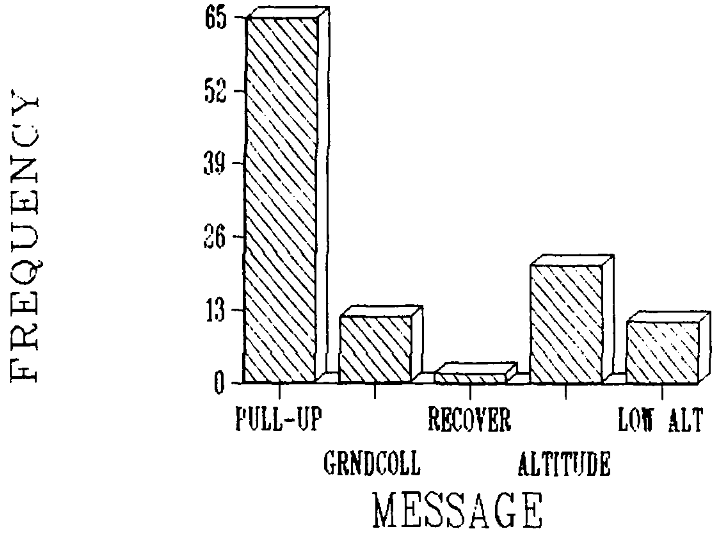

Figure 1a. <u>Frequency as a function of proposed voice messages for the GCAS warning</u>.

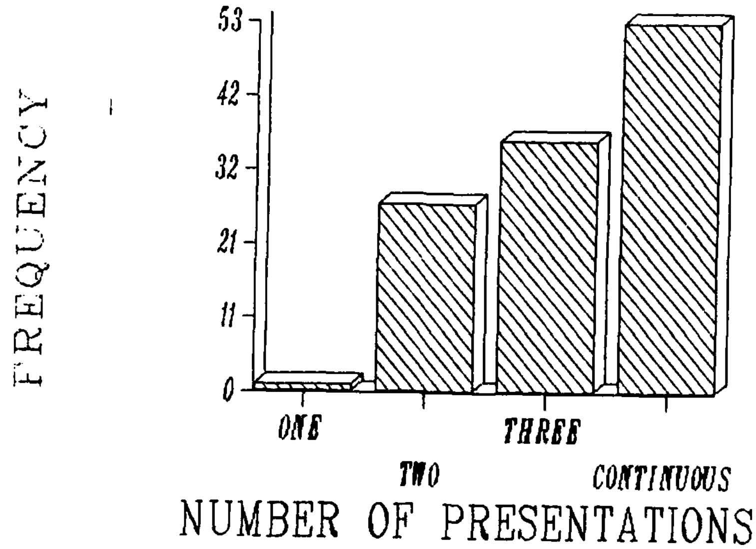

Figure 1b. <u>Frequency as a function of the number of presentations for the GCAS warning</u>.

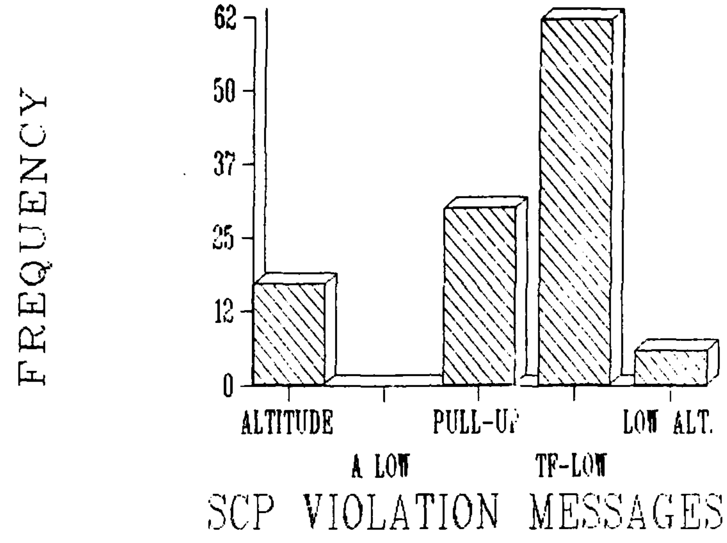

Figure 2a. Frequency as a function of proposed voice messages for the SCP violation warning.

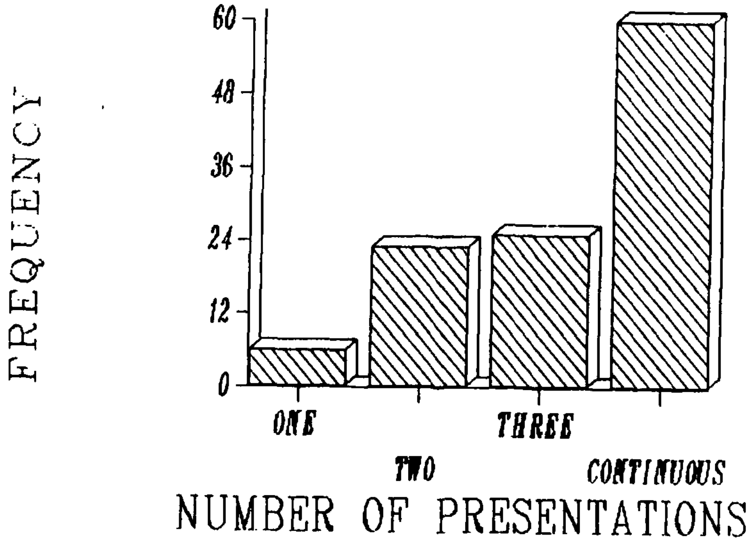

Figure 2b. Frequency as a function of the number of presentations for the SCP violation warning.

of votes (62). The Chi Square value (105) was significant at the .95 confidence level.

Similar to the GCAS warning, most crew members preferred that this warning be presented until the pilot makes a response (i.e. flies above 83% of the SCP). The data are shown in Figure 2b). Statistically significant frequency differences ($X^2 = 54$, $p<.05$) were found between the four available options.

AOA/SS Caution. The AOA/SS caution data are shown in Figures 3a and 3b. As suggested by Figure 3a, a statistically significant Chi Square ($X^2 = 34.69$, $p<.05$) implied that the message ALPHA-SIDE-SLIP was preferred by most crew members over the other proposed messages, A.O.A., ALPHA, and A.O.A.S.S., with 44 votes. 16 of the 119 subjects decided not to select any of the available options, while stating in the comments section that they believed the AOA/SS caution was not necessary. A complete list of all the pilots' comments is shown in Appendix B.

When asked about their preference in the presentation format, the crew members' questionnaire data (shown in Figure 3b) indicated that presenting the AOA/SS caution message three times would be preferred. The statistical analysis resulted in significant differences between the four available options ($X^2 = 34.69$, $p<.05$).

Autopilot Failure Caution. The Autopilot Failure Caution proved to be the only question to produce unclear results (data are shown in Figure 4a). A statistically significant Chi Square ($X^2 = 88.5$, $p<.05$) indicates a clear preference between the message selected with the highest frequency, AUTOPILOT-FAILED, and the two lowest frequency messages, AUTO-FAIL and AUTO-MALFUNCTION. However the second highest selected message, AUTOPILOT, had only 7 votes less

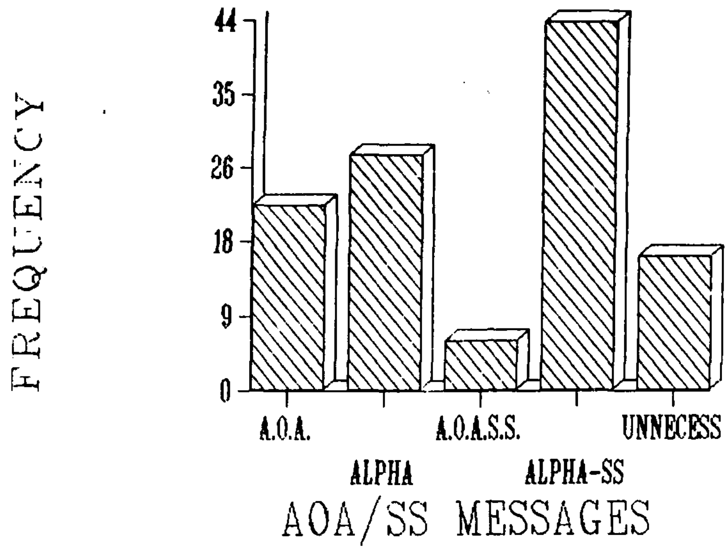

Figure 3a. Frequency as a function of proposed voice messages for the AOA/SS caution.

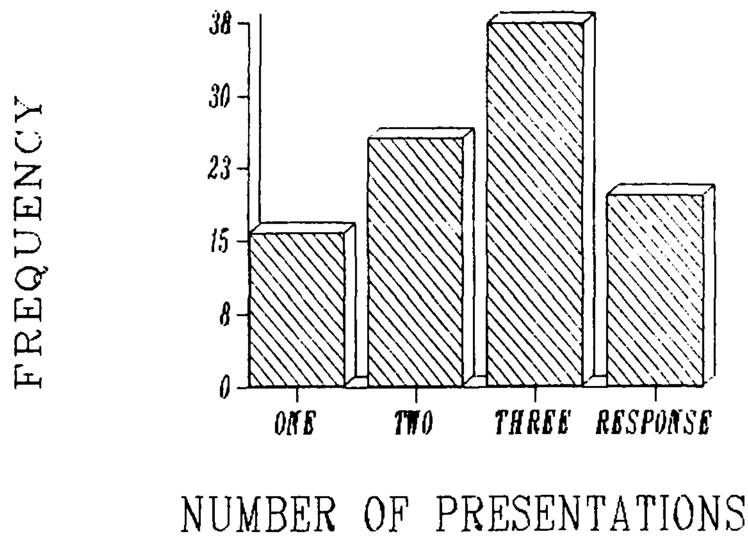

Figure 3b. Frequency as a function of the number of presentations for the AOA/SS caution.

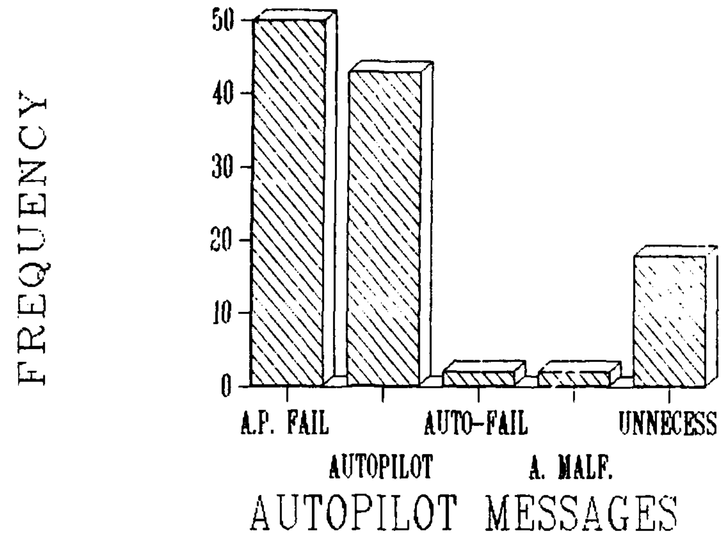

Figure 4a. Frequency as a function of proposed voice messages for the autopilot failure caution.

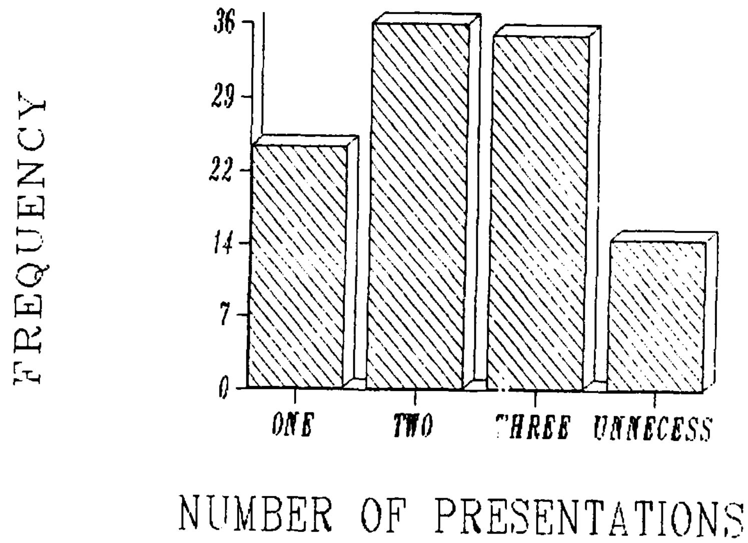

Figure 4b. Frequency as a function of the number of presentations for the autopilot failure caution.

than AUTOPILOT-FAILED (a difference of only 6.6 percent) Therefore, it will be assumed that no realistic difference in message preference exists between AUTOPILOT and AUTOPILOT FAILED.

Also unclear, was the frequency of presentation selection made by the crew members (data are shown in Figure 4b). Again, while a significant Chi Square analysis was computed (X^2 = 10.8, p<.05), the crew members' data were not clear in indicating their preference between two and three repetitions. As with the message selection data, it will be assumed that the crew members do not have a strong preference between presenting this caution two or three times.

General Voice Related Items

Prioritization. When asked to prioritize the warning and caution messages, the crew members had definite ideas on the order of message presentation. An inspection of the data, shown in Figure 5, suggests the following: Most crew members would like for the GCAS warning to take precedence over all other voice message presentations (X^2 = 256, p<.05). The SCP violation warning was ranked as second priority (X^2 = 201, p<.05), with the AOA/SS caution as third (X^2 = 165, p<.05), and finally the autopilot failure caution as fourth (X^2 = 233, p<.05). It also appears that the crew members prefer to prioritize the warning messages (GCAS and SCP violation) higher than the caution messages (AOA/SS and Autopilot failure). The warning messages were selected as first or second priority 94 percent of the time and as third or fourth priority only six percent of the time. The caution selections were reversed: They were expressed as first or second only six percent of the time, while third and fourth 94 percent of the time.

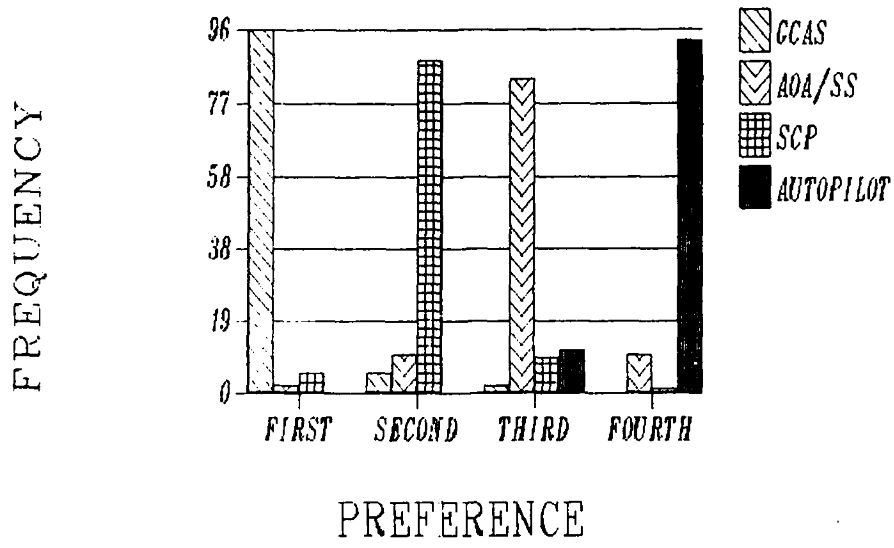

Figure 5. Frequency as a function of prioritization for each level.

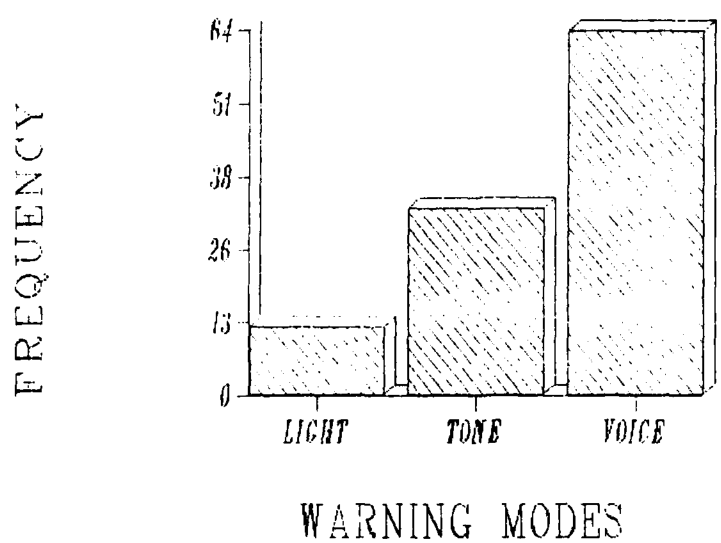

Figure 6. Frequency as a function of preferred warning modes.

Warning Mode. As shown in Figure 6, it appears that most crew members indicated a preference for the voice warning mode over light and tone. The frequency analysis resulted in significant differences between the three proposed options ($X^2 = 36.3$, $p<.05$).

It should be noted in this section that the idea of modal redundancy was not part of the data being elicited. It is well documented that a warning presented by a light and accompanied by a voice message will increase its probability of being detected by the user. For instance, if a pilot is looking and processing information outside the cockpit, he or she may miss a visual cue, but not an auditory one. On the other hand, if the auditory channel is overloaded with information, a pilot may miss a voice message but still be able to detect a visual cue (Werkowitz, 1979).

Stall Warning Mode. When given the option as to voice or tone as a warning for a stall conditions, there is no doubt about which mode the crew members prefer. The data, shown in Figure 7, show the tone warning as favored over a voice warning. Again the statistical analysis verified the above statement with a significant difference between tone and voice ($X^2 = 42.2$, $p<.05$).

It should be stated, however, that the sample of subjects used for data collection may be biased, in that none of them had previous experience with a stall voice warning. Despite their bias, the crew members seem to like what they currently have on the aircraft and would like to keep the tone as the warning mode for a stall condition.

Stall Message Preference. In case the stall warning would be presented by a voice message, the crew members would prefer the message STALL over RECOVER (the data are shown in Figure

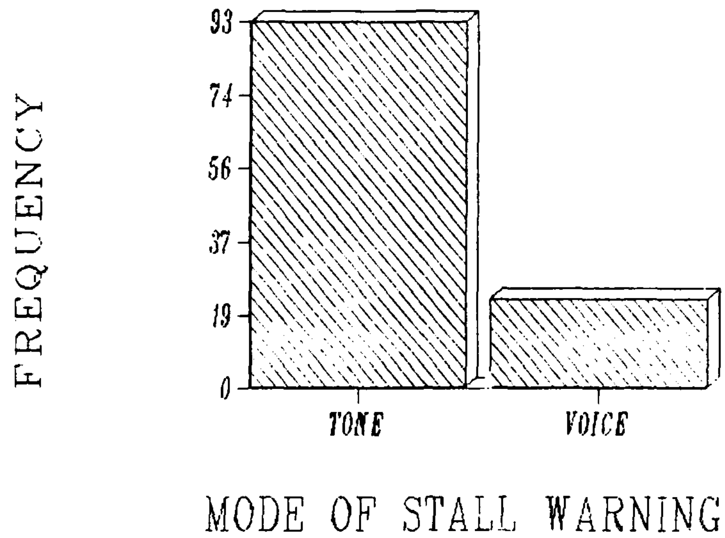

Figure 7. Frequency as a function of stall warning mode.

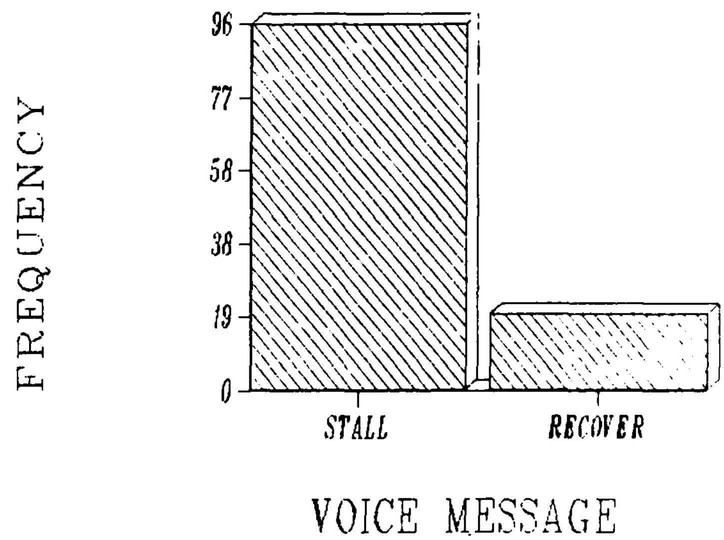

Figure 8. Frequency as a function of stall message preference.

8). The Chi Square analysis was statistically significant (X^2 = 49.8, $p<.05$).

Voice Gender Preference. The preference frequency data on the gender of the voice message are shown in Figure 9. Almost 86 percent of the subjects would prefer hearing a female rather than a male voice presenting the message. The statistical analysis was found to be significant (X^2 = 58.9, $p<.05$). This may be related to the fact that most voices on the air waves are of male speakers, and the female voice provides the crew with a distinctive voice which is different from all others. However, this distinctiveness factor may not be everlasting, since more women are becoming part of the Air Force's fighting regime.

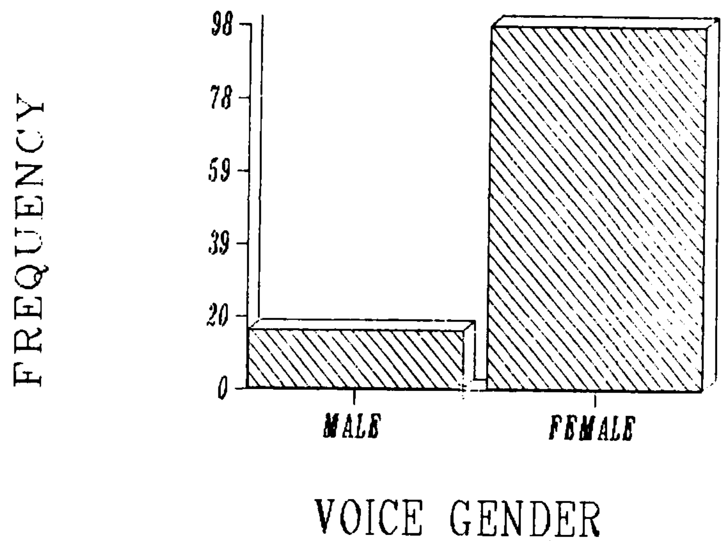

Figure 9. Frequency as a function of voice gender preference.

PHASE II
VOICE STUDY SIMULATION

The intent of the second phase of this study was to have operational F-111 pilots experience the presentation of the proposed voice messages in a cockpit environment, and provide the SPO with feedback, as to their preference, on some design options relevant to the newly proposed VMU.

Method

Subjects

Six TAC and three SAC operational pilots participated in the simulation study. An attempt was made to insure that the pilots were representative of the overall population by varying the age and the level of flying experience. The age of the pilots ranged from 26 to 45 with a mean of 32.5, and a standard deviation of 7.2 years. Flying experience varied from 120 to 4100 total hours, with a mean of 1970 and a standard deviation of 1347 hours. The sample of pilots represented four F-111 Air Force bases: Plattsburg AFB (SAC, 2 pilots); Mountain Home AFB (TAC, 3 pilots); Cannon AFB (TAC, 3 pilots); and Pease AFB (SAC, 1 pilot).

Apparatus

Facility. The study was conducted at the Crew Station Design Facility (CSDF), which is a U.S. Air Force simulation facility that belongs to the Aeronautical Systems Division (ASD) of Air Force Systems Command. The CSDF government personnel are assigned by the Human Factors Branch (ASD/ENECH). The facility (shown in Figure 10) is used to

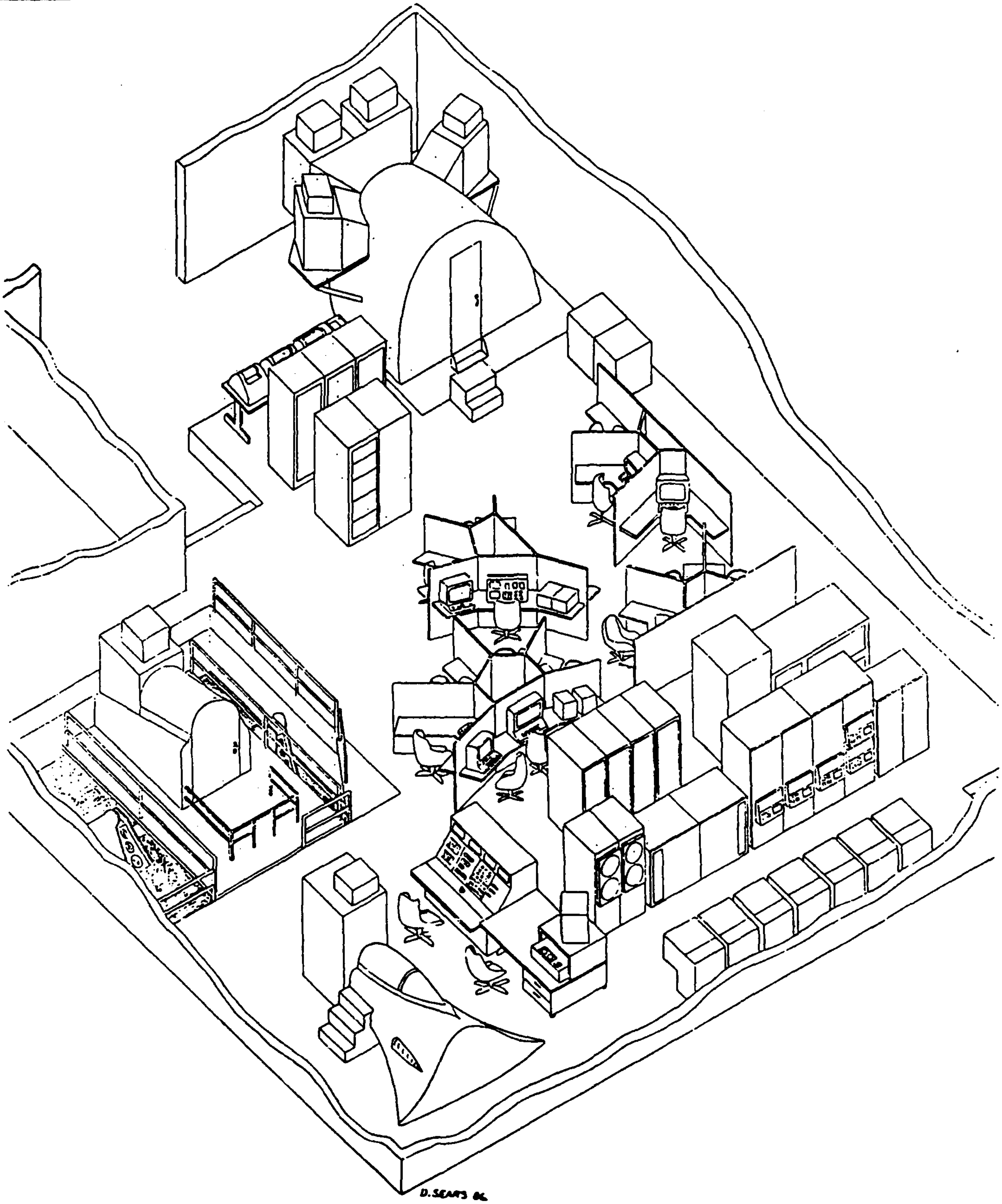

Figure 10. Crew Station Design Facility simulator area.

conduct human engineering and system design mechanization studies in support of a variety of System Program Offices.

Simulator. A photograph of the FB-111 simulator is shown in Figure 11. The simulator is resting on a three degree of freedom motion platform (not used in current study), and includes such major components as the control loading assemblies, seats, canopies, and visual window. An Advanced Simulator Technology interface cabinet is mounted on the nose of the cockpit to interface the simulator with the Gould computer complex. A walk-way with railings is installed around the simulator to insure pilots' safety and allow for easy access in and out of the cockpit. The majority of the instrumentation on the left side of the cockpit are available to the pilot. The FB-111 software package contains all flight, engine, atmosphere, weights, balances modules, and a data dictionary of all FB-111 data variables, as well as several other specific commons and datapools. All Linear Function Interpolation curves are validated, and all the Avionics Modernization Program (AMP) configured pages for the Central Display Unit (CDU) and the Multi Function Displays (MFD) are incorporated into the software package.

Computer Complex. The simulator is connected to a series of large and small computer systems. This computer complex includes five Gould series 32/7780, one Gould concept 32/8780, two PDP 11/34, three PDP 11/35, and two Silicon Graphics Iris Computer Aided Design Stations (one Iris 2400, and one Iris 3020).

Experimenter's Console. The experimenter's console, shown in Figure 12, is located approximately 12 feet away from the simulator. It includes a complete intercom system, together with communication to and from the pilot inside the simulator. The console's displays duplicate the simulator's

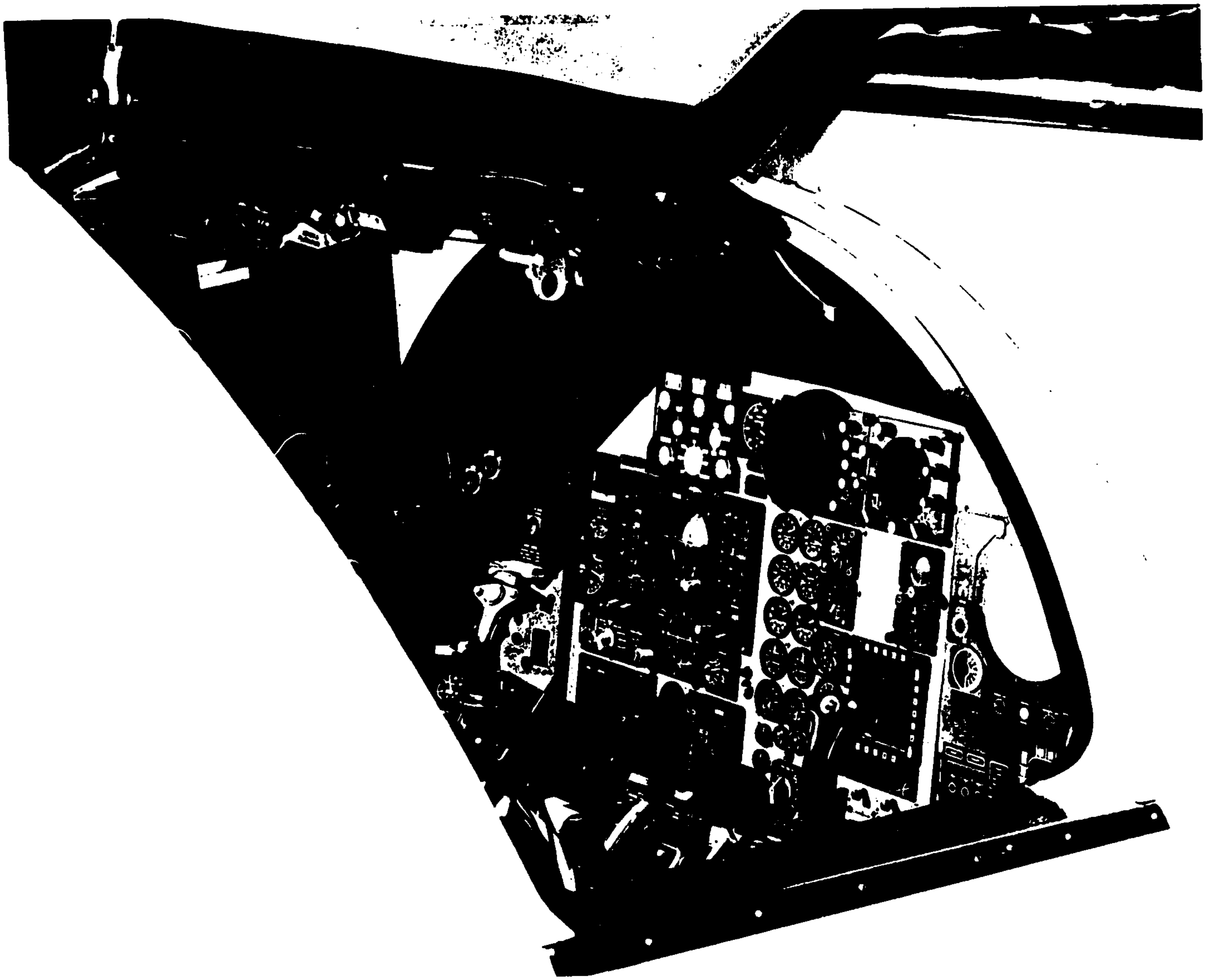

Figure 11. The FB-111 simulator.

Figure 12. The experimenter's console.

visual scene, instruments, and displays, and are used to monitor the pilot's performance. Furthermore, the console's controls permit the experimenter to start, stop, and reset the simulation at any time.

TABLE 1. <u>The eight voice messages that were evaluated in the simulator (along with the time it took to present each voice message)</u>.

FAILURE	MESSAGE	TIME (in seconds)
GCAS	PULL-UP	0.420
	CLIMB	0.506
SCP VIOLATION	TF-LOW	0.850
	ALTITUDE	0.830
AOA/SS	ALPHA SIDE SLIP	1.050
	ALPHA	0.510
AUTOPILOT FAILURE	AUTOPILOT	0.720
	AUTOPILOT FAILED	1.000

Voice Messages. Eight voice messages, shown in Table 1, were recorded on an Amiga micro computer by a female employee of the CSDF. The employee, who had a distinctive and mature mid-western voice, presented the messages in a formal and impersonal manner. The Amiga used a high speed voice digitizer (Future Sounds), with a sampling rate of 10,000 samples per second, to convert the messages from analog to digital format. The Amiga was thereafter connected to

the main frame computers using an RS-232 interface, and transmitted the messages to the pilot's head set (an ASTROCOM model number 20680 with MX-2508/A/C pads) through the intercom channel. The length of time it took to articulate each message ranged from 0.42 to 1.05 seconds. The time data are also shown in Table 1.

Audio Systems. Background communication was simulated by an audio tape which was replayed throughout half the missions of the experiment, on a Technics by Panasonic model number RS-263AUS tape player, and transmitted to the pilot's head set through the intercom channel.

Procedure

The pilots were instructed to fly the simulator, head down, either in a manual or an automatic Terrain Following (TF) mode. During manual TF missions, the pilots encountered GCAS and SCP violation warnings, while the AOA/SS and Autopilot Failure cautions were heard throughout the auto TF missions. Each time a voice message was activated, the pilots were instructed to immediately deactivate the failure by manually pressing the appropriate switch located on the flying stick. The SCP and Autopilot failure were responded to by pressing the paddle switch, while GCAS and AOA/SS failures were deactivated by pressing the trigger.

Throughout half the missions, background communication was presented by playing an audio tape of a combat mission, recorded during the Vietnam war, and transmitted to the pilot through the head set. The pilots were instructed to ignore background communication, which was irrelevant to the success of their mission.

Each pilot flew one practice run of each of the four

experimental missions, and was exposed to all eight voice messages. The pilot then flew the same four missions with data collection turned on. Each mission lasted approximately 12 minutes. The warning and caution messages were presented to the pilot at an average of 30 seconds, with a standard deviation of 10 seconds, for a total of 24 events (six repetitions per message). At the completion of the flying missions, the pilots were asked to complete a short survey relevant to the voice messages being evaluated and to the fidelity of the simulator. Each pilot participated in the study for approximately three hours, which included a 15 minute break between replications.

VMU Mechanization

All eight messages were presented to the pilot through the intercom channel at approximately 90 dB. In order to maintain consistency across subjects and conditions, pilots were told not to change the volume control setting. Warning messages (Pullup, Climb, Altitude, and TF-Low) were mechanized in such a way that the messages were continuously presented to the pilot until the corrective action was completed, with an inter-message interval of 500 milliseconds. The caution messages, on the other hand, were also presented with an inter-message interval of 500 milliseconds, except that the messages were always repeated three times irrespective of the status of the response. This format was influenced by the results found in the first phase of this evaluation. The format makes sense in that normally, warnings require some type of an immediate manual response, whether the pilot is actively pressing a button or pulling on the flying stick. On the other hand, cautions, which may still be critical to the operation of the aircraft, do not always require a corrective action.

Design

The experiment was designed to compare pilots' objective and subjective data to either of two messages per warning. The objective data included response time, from onset of the message until the trigger or paddle switch was pressed, and response accuracy. Response time calculations were independent from the message presentation time. Also of interest to this evaluation was the effect of background communication on the comprehension and recognition of the messages. Therefore, throughout half the missions, background communication was presented as an auditory interference and general noise factor.

The subjective data (gathered through the questionnaire) elicited preference selections between the two messages (per failure) that were experienced throughout the study. The pilots were also asked to subjectively evaluate the location and nomenclature of the new warning and caution lights that corresponded with the voice messages.

Simulator Results

Objective Data

Pilots' mean correct response time and percent response accuracy data were analyzed using four separate 2X2 two way repeated measures analyses of variance (ANOVA); one ANOVA per failure condition. The independent variables were voice message (two messages per failure condition) and background communication (ON versus OFF). The response accuracy analyses were performed in order to test for possible response/accuracy trade-offs. Throughout the results section, only statistically significant ($p < .05$) F values will be reported.

TABLE 2. Pilots' mean response time and percent response accuracy for the GCAS failure.

RESPONSE TIME

	BACKGROUND COMMUNICATION		
	ON	OFF	MEAN
CLIMB	1.086	0.959	1.023
PULLUP	1.038	1.098	1.068
MEAN	1.062	1.029	

PERCENT ACCURACY

	BACKGROUND COMMUNICATION		
	ON	OFF	MEAN
CLIMB	94	94	94
PULLUP	98	93	95
MEAN	96	94	

GCAS Warning. An inspection of the GCAS means, shown in Table 2, indicates that pilots' response times were affected neither by the voice message nor by the background communication. The analysis of variance resulted in a non-significant two-way interaction as well as non-significant main effects of message and background communication.

The response accuracy data coincided with the response time data, in that no significant interaction or main effects resulted from the analysis.

SCP Warning. The means for the SCP violation warning are shown in Table 3. The response time ANOVA resulted in a statistically significant main effect of background communication ($\underline{F}(1,8) = 6.66$, $\underline{p} < .05$). An inspection of the means in Table 3 indicates that pilot response times were 119 ms slower when background communication was ON in comparison with no background communication (OFF). Non-significant differences were identified for the two-way interaction as well as the main effect of voice message.

Despite a 10 percent accuracy advantage for TF-LOW over ALTITUDE, the means were not found to be significant. However, the standard deviations for the two messages were calculated at 39 and 29 percent. These differences were large enough to negate any indication for a possible trend. The response accuracy data offered no significant differences for the interaction or the main effect of background communication.

AOA/SS Caution. The analysis of variance on pilot response time resulted in a significant main effect of voice message, $\underline{F}(1,8) = 7.42$, $\underline{p} < .05$. An inspection of the means, shown in Table 4, indicates that the pilots responded faster to ALPHA (1.096 seconds) than to ALPHA SIDE SLIP (1.189 seconds). The two way interaction and the main effect of background communication were not found to be statistically significant.

TABLE 3. Pilots' mean response time and percent response accuracy for the SCP failure.

RESPONSE TIME

BACKGROUND COMMUNICATION

	ON	OFF	MEAN
ALTITUDE	1.176	1.076	1.126
TFLOW	1.222	1.087	1.154
MEAN	1.200	1.081	

PERCENT ACCURACY

BACKGROUND COMMUNICATION

	ON	OFF	MEAN
ALTITUDE	83	79	81
TFLOW	93	89	91
MEAN	88	84	

TABLE 4. Pilots' mean response time and percent response accuracy for the AOA/SS failure.

RESPONSE TIME

	BACKGROUND COMMUNICATION		
	ON	OFF	MEAN
ALPHA	1.138	1.054	1.096
ALPHA SIDE SLIP	1.157	1.222	1.189
MEAN	1.147	1.138	

PERCENT ACCURACY

	BACKGROUND COMMUNICATION		
	ON	OFF	MEAN
ALPHA	93	96	94
ALPHA SIDE SLIP	91	98	94
MEAN	92	97	

The response accuracy ANOVA identified no statistically significant interaction or main effects.

Autopilot Failure Caution. The complete list of means is shown in Table 5. The results of the ANOVA for pilot response time data identified a significant two-way interaction between voice message and background communication ($\underline{F}(1,8) = 9.26$, $\underline{p} < .05$). An inspection of Figure 13 suggests that while no difference in response time data seems to exist between the two messages, when background communication was off, the background communication "ON" condition affected pilot performance in such a manner that response time data were found to be faster to the message AUTOPILOT (1.048 seconds) than to the message AUTOPILOT FAILED (1.163 seconds). The results of the response time ANOVA were non-significant for the main effects of voice message and background communication.

As with the previous accuracy data, neither the two-way interaction nor the main effects were found to be statistically significant throughout the analysis of variance.

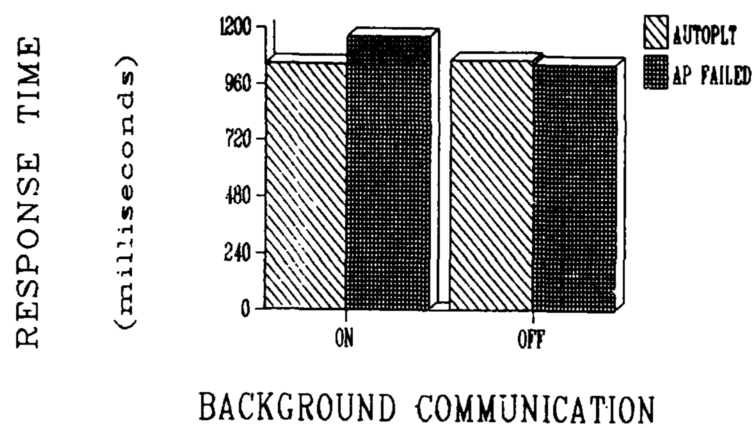

Figure 13. Pilots' mean response time data as a function of voice message and background communication

TABLE 5. Pilots' mean response time and percent response accuracy for the autopilot failure.

RESPONSE TIME

	BACKGROUND COMMUNICATION		
	ON	OFF	MEAN
AUTOPILOT	1.048	1.069	1.059
AUTOPILOT FAILED	1.163	1.048	1.105
MEAN	1.106	1.059	

PERCENT ACCURACY

	BACKGROUND COMMUNICATION		
	ON	OFF	MEAN
AUTOPILOT	89	87	88
AUTOPILOT FAILED	96	85	91
MEAN	96	86	

Subjective Data

Due to the small number of pilots used throughout the simulation effort, it was decided by the experimenter that a formal statistical analysis using Chi Square would not be appropriate. However, for the sake of data interpretation, a frequency totaling two thirds of the total sample (six pilots) would be considered a majority opinion.

The frequency data for the preferred voice messages are shown in Figures 14 through 17. The bar graphs indicate a majority preference for the following voice messages: TF-LOW for SCP violation warning, and ALPHA SIDE SLIP for AOA/SS. No clear preference was indicated for the GCAS warning or the Autopilot Failure caution.

The following paragraph reflects other subjective data relative to the mechanization of the F/FB/EF-111 VMU (The data are shown in Figures 18 through 20): Six of the pilots confirmed the need for a redundant GCAS mode (such as light); eight out of nine pilots believed that the 500 milliseconds inter-message-time was optimum (pilot nine expressed concern that the inter-message-interval was too long); the same eight out of nine pilots believed that the three time caution repetition was optimum (pilot nine recommended to decrease the number of presentations); all nine pilots responded affirmatively when asked about the nomenclature and location of the AOA/SS and the FCS caution lights indicating an Autopilot Failure. Finally, all nine pilots believed that the use of the Radar Alt Low light (flashing) as a warning indicator for an SCP violation is acceptable.

Comments elicited from the pilots in regard to the above data are listed in Appendix B.

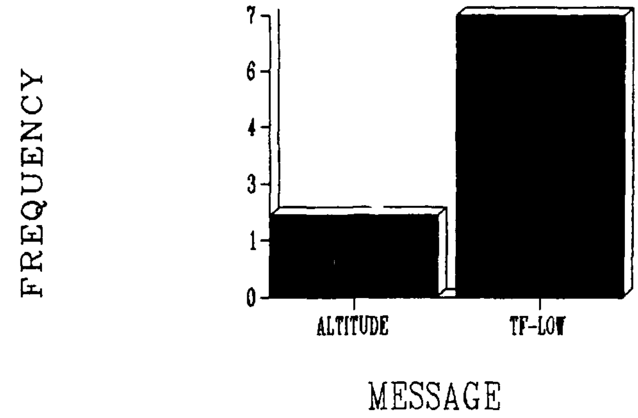

Figure 14. Pilots' preference Frequency as a function of the two SCP violation voice messages.

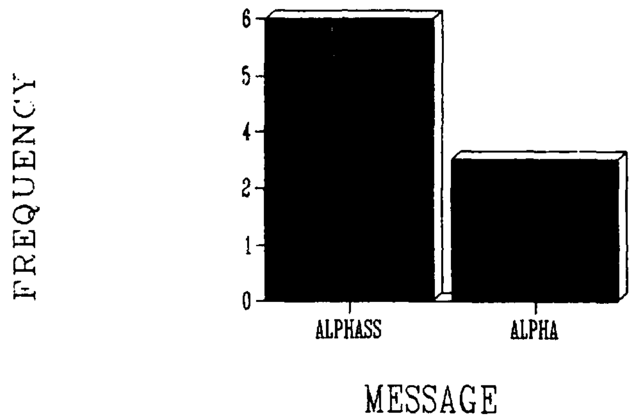

Figure 15. Pilots' preference Frequency as a function of the two AOA/SS caution voice messages.

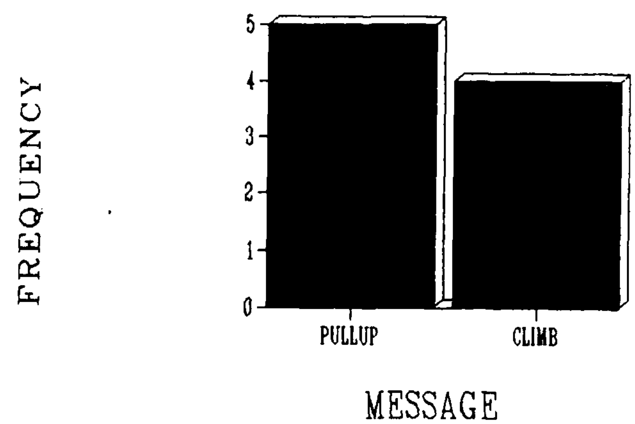

Figure 16. Pilots' preference Frequency as a function of the two GCAS warning voice messages.

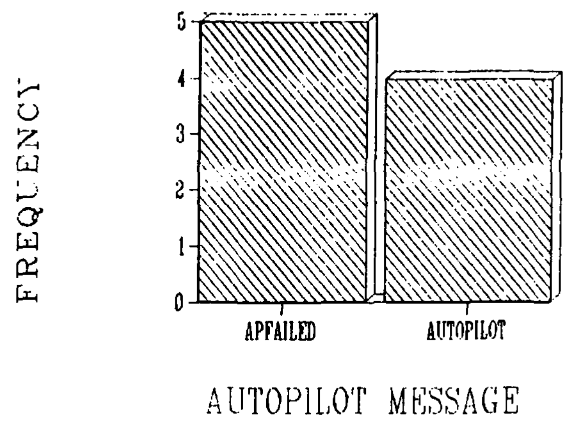

Figure 17. Pilots' preference Frequency as a function of the two Autopilot Failure Caution voice messages.

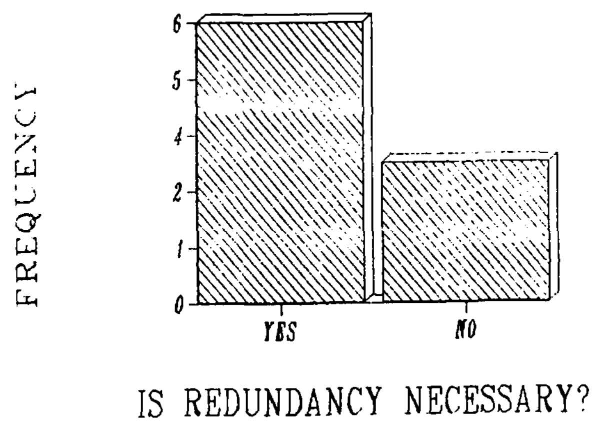

Figure 18. Pilots' preference Frequency as a function of the GCAS redundancy question.

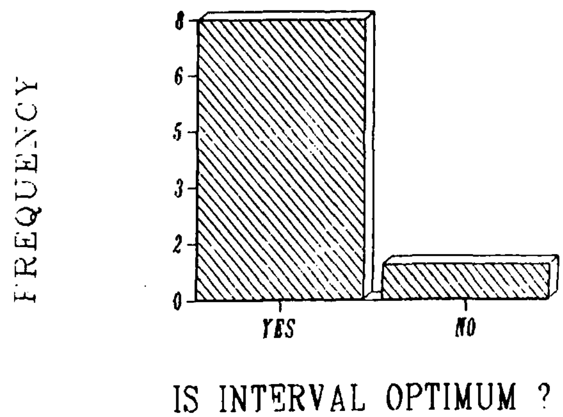

Figure 19. Pilots' preference Frequency as a function of the inter-message-time interval.

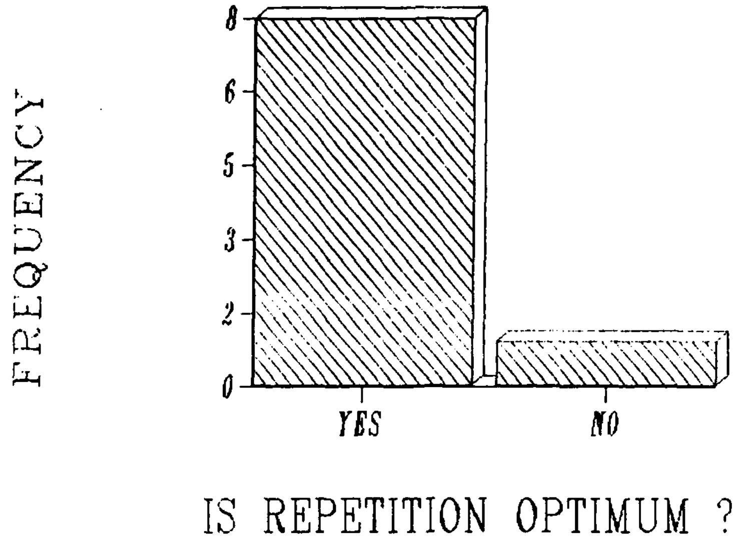

Figure 20. Pilots' preference Frequency as a function of the repetition of the caution voice messages.

GENERAL DISCUSSION AND CONCLUSION

The voice message system in the F-111 aircraft should provide a crucial capability to the crew in the areas of workload reduction and safety in flight. It is intended that the production of the system provide highly acceptable results realizing the inevitable tradeoffs between system quality and computer memory. The results of this evaluation as well as the system requirements should serve as a guide to the development of this voice message unit.

Werkowitz (1980) describes four elements which are necessary for an operator to receive and use a spoken message: 1) Awareness that a message is being presented, 2) Recognition of the words of the message, 3) Understanding the message, and 4) Knowledge of how to use the information. As a result of research and experience, many guidelines and requirements exist which apply to the development of a voice message system and can be correlated with the above listed elements and the results of this evaluation.

Message Awareness

The awareness that a message is being presented relates to the method of presentation of the message. MIL-STD-1472 dictates that verbal warning signals shall consist of an initial alerting signal (non-speech) to attract attention and to designate the general problem area. Due to the response time critical issue associated with some of the warnings, this requirement becomes questionable and, in fact, is not recommended for most uses of verbal warnings. The standard also states that the voice used in recording verbal warning signals shall be distinctive and mature. Typically in voice message systems, a female voice has been used for two main

reasons: (1) Due to its higher frequency than the male voice; and (2) to make it stand out from radio communications which are predominantly male voices, although, the influx of women into the services may eventually decrease the efficacy of this approach. The evaluation showed that a female voice is preferred by the F/FB/EF-111 pilots surveyed. MIL-STD-411D, Aircrew Station Signals, dictates that verbal warning signals shall only be used to complement red warning or other critical visual signals. This redundancy is evident in the design of this voice warning system. Each of the cautions (AOA/SS and autopilot failure) are redundant to caution lights on the master caution panels. The SCP violation warning, in turn, is redundant to the Radar Altitude Low warning light. The GCAS warning represents a new addition to the aircraft with no visual redundancy at this time. This is in contradiction with the military specifications (MIL-STD-411), of which the CSDF agrees with. A light signal should be the primary mode of presentation, which may then be complemented by a voice message. Repetition of the messages by the warning system represents a further aid to awareness. The pilots surveyed favored three statements of the AOA/SS caution, two or three statements of the autopilot failure caution, and, due to the criticality of the warnings, repetition of the GCAS and SCP violation warnings until action is taken by the pilot.

Recognition of words

The recognition of the words of the message determines the effectiveness of the communication system. This element is dependent upon the nature of the speech material; the relevant characteristics of the talker and listener; the conditions under which the radiation, transmission, and reception of the speech wave occur; and the characteristics

of the communication system. Voice communication may be degraded by a variety of system and environmental factors that include electrical or acoustical noise or both, radio interference, jamming, communication signal processing and various other factors that prohibit effective communication. Important in the recognition of the words is the intensity and the intelligibility of the system. MIL-STD-1472 presents requirements for intensity, stating that verbal alarms for critical functions shall be at least 20 dB above the speech interference level at the operating position of the intended receiver. The speech interference level (SIL) is the arithmetic average of the sound pressure levels of the interfering noise, in decibels, in the four octave bands centered on the frequencies 500, 1000, 2000 and 4000 Hz, respectively. MIL-STD-1800, Human Engineering Performance Requirements for Systems, specifies three recommended methods for assessing the speech intelligibility of a given system: 1) The ANSI standard method of measurement of phonetically balanced (PB) monosyllabic word intelligibility, 2) The modified rhyme test (MRT), and 3) the articulation index (AI) calculations.

Analytical studies of voice warning system performance, environmental influences and the man-in-the-loop element must be carried out under carefully controlled conditions that simulate to the greatest extent possible, the practical, operational situations of concern. As speech intelligibility is the most critical aspect of a voice message system, it is more advantageous to conduct laboratory intelligibility testing with the communication system in as near an operational configuration as possible. All listeners should wear standard custom fitted flight helmets, earphones, and oxygen masks through which they receive breathing air. Furthermore, the noise environment in which the system is to be eventually used should be emulated as closely as possible. In all cases involving evaluation of the intelligibility

and/or quality of a speech synthesis system, the human listener is the ultimate discriminator.

Understanding of message

With respect to the understanding of the message, MIL-STD-1472 states that verbal warning signals shall consist of a brief standardized speech signal (verbal message) which identifies the specific condition and suggests appropriate action. Also, in selecting words to be used in audio warning signals, priority shall be given to intelligibility, aptness, and conciseness in that order. It was with these ideas in mind that this evaluation was done, emphasizing the aptness and conciseness of the messages. From the alternatives offered in the questionnaire, for the various messages, preferred messages were determined. PULL-UP was chosen for the GCAS warning with ALTITUDE as a not so close second. In the simulation study, PULL-UP was evaluated against CLIMB, a write-in choice by a few of the respondents, with no significant results. This was done to allow for ALTITUDE to be evaluated as the SCP violation warning. Headquarters Tactical Air Command has issued the recommendation that PULL UP be used for the GCAS warning, and it is intended to be, with specific exceptions. For the take-off and landing modes of the aircraft, pulling up may be the incorrect maneuver and result in a stall or crash. For this application, a different message, i.e. ALTITUDE or CLIMB, might be more appropriate. TF-LOW was chosen for the SCP violation warning with PULL-UP and ALTITUDE as a not so close second and third, respectively. In the simulation, TF-LOW was evaluated against ALTITUDE, allowing for PULL-UP to be evaluated as the GCAS warning, with TF-LOW showing a clear preference once again. ALPHA SIDE-SLIP was chosen for the AOA/SS caution with ALPHA as second choice. The simulator evaluation showed ALPHA-SIDE-SLIP preferred two to one over ALPHA. AUTOPILOT

FAILED was chosen as the autopilot failure caution with AUTOPILOT as a close second. The simulator evaluation did not show a significant preference.

Prioritizing the Messages

It is possible that two or more of the failure conditions may occur simultaneously. In such a condition, the messages need to be prioritized so that the most critical message is presented first. If such prioritization is deemed appropriate for the subject aircraft, the following order would be most appropriate: (1) GCAS, (2) SCP violation, (3) AOA/SS, and (4) Autopilot Failure.

Knowledge of Use

The knowledge of how to use the information in the case of pilots relates to training in the aircraft. MIL-STD-411D, Aircrew Station Signals, dictates that verbal warning signals shall be audible signals in verbal form indicating the existence of a hazardous or imminent catastrophic condition requiring immediate action. The pilots should be thoroughly trained in the response methodology to such warnings.

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Department of Defense (1981). Human Engineering Design Criteria for Military Systems, Equipment, and Facilities (MIL-STD-1472C). Washington, DC: Author.

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APPENDIX A

VOICE WARNINGS SURVEY

The following survey deals specifically with the voice warning messages that will be implemented in the cockpit of the F/FB/EF-111 aircraft as part of the new Digital Flight Control System (DFCS). Your serious cooperation in the completion of the survey will insure that the incorporated voice messages will be most consistent with the flight crew population's terminologies and definitions of the relevant warnings. Furthermore, the results of the survey will be used in man-in-the-loop simulation at the Crew Station Design Facility (ASD/ENECH-CSDF, Wright Patterson AFB) in order to experimentally evaluate the voice messages. This in turn could insure optimal crew members' performance, with faster response times and lower levels of workload demand.

For each of the following multiple choice questions, circle what you think would be the most appropriate option. For each question, an additional section is provided so you may include comments which are relevant to the topic in question. This section will also allow you to add any additional options (such as another voice message) which were not previously listed. However, make sure you select one of the available options before you include any comments.

Please use your <u>personal judgment</u> in responding to all the items covered throughout the survey. All surveys should be completed and returned to ______________, at ___________, by 18 November, 1987.

PERSONAL DATA:

NAME: ______________________________

RANK: ______________________________

AERO RATING: ______________________________

ORGANIZATION: ______________________________

OFFICE SYMBOL: ______________________________

DUTY STATION: ______________________________

FLYING HOURS: ______________________________

DESCRIBE ANY PRIOR EXPERIENCE (IF ANY) WITH VOICE WARNING MESSAGES: ______________________________

____

VOICE WARNING QUESTIONS

A. GROUND COLLISION AVOIDANCE SYSTEM (GCAS). This voice warning will be capable of providing the necessary enunciation to effectively alert the crew of an impending ground collision.

1. Which of the following voice messages would you consider to be most appropriate for the GCAS warning ?

   (a) Pull-Up
   (b) Ground-Collision
   (c) Recover
   (d) Altitude
   (e) Low Altitude

   COMMENTS: ____________________

   ____

2. How many times should the GCAS warning message be repeated with each incident ?

   (a) Once
   (b) Twice
   (c) Three times
   (d) Until the conditions to affect the recovery are completed

   COMMENTS: ____________________

   ____

B. AOA/SS FAILURE WARNING. (Angle Of Attack/SideSlip) This caution will indicate that there is a performance degradation in AOA limiter and/or adverse yaw compensation. The specifics of the cause are attributable to one of the following failures:

Airborne:
* AOA Probe Miscompare
* Dual Probe Transmitter Failure
* Dual Probe Heater Failure
* Dual Roll Rate Failure
* Series Trim Actuator Failure
* Total Aileron Position Failure Flaps Up
* Large Initial SS or Flight Control Disconnect with Flaps Down

Ground:
* Probe Heat is Deselected
* Probe is Selected and Heaters in either LAOA, RAOA, or Beta have Overheated

1. Which of the following voice messages would you consider to be most appropriate for the AOA/SS caution ?

   (a) AOA
   (b) Alpha
   (c) AOA-SS
   (d) Alpha-Side-Slip

   COMMENTS: ______________________________

   ____

2. How many times should the AOA/SS caution message be repeated with each incident ?

(a) Once
(b) Twice
(c) Three times
(d) Until the pilot completes the corrective action

COMMENTS: ______________________________

____

C. SET CLEARANCE PLANE (SCP) VIOLATION (83%). The warning is initiated when the aircraft flies below 83% of the selected SCP altitude.

1. Which of the following voice messages would you consider to be most appropriate for the SCP violation warning ?

(a) Altitude
(b) A Low
(c) Pull-Up
(d) TF low
(e) Low Altitude

COMMENTS: ______________________________

____

2. How many times should the SCP violation warning message be repeated with each incident ?

(a) Once
(b) Twice
(c) Three times
(d) Until the aircraft is above 83% of SCP

COMMENTS: ____

____

D. AUTOPILOT FAILURE CAUTION. This caution indicates that the autopilot is malfunctioning. The failure may occur either when the pilot is engaging autopilot, or while the aircraft is already in autopilot mode. The failure will cause the autopilot to automatically disengage.

1. Which of the following voice messages would you consider to be most appropriate for the autopilot failure caution ?

(a) Autopilot Failed
(b) Autopilot
(c) Auto Fail
(d) Auto Malfunction

COMMENTS: ____

____

2. How many times should the autopilot failure caution message be repeated with each incident ?

   (a) Once

   (b) Twice

   (c) Three times

   COMMENTS: ________________________________

   ____

E. GENERAL VOICE WARNINGS. The following questions will discuss the voice message mechanization process in general.

1. Which of the failures should take precedence, in case two or more of them need to be simultaneously presented to the pilot. Rank the failures in the prioritized order that you consider to be optimum.

   ( ) GROUND COLLISION AVOIDANCE SYSTEM

   ( ) AOA/SS FAILURE

   ( ) SCP VIOLATION

   ( ) AUTOPILOT FAILURE

   COMMENTS: ________________________________

   ____

2. As a general rule, which of the following warning "mode" is most effective in attracting crew members' attention in a cockpit environment ?

(a) Light
(b) Tone
(c) Voice

COMMENTS: ______________________

____

3. As a general rule, Which voice format would you consider to be most efficient in attracting your attention ?

(a) Human female voice
(b) Human male voice

COMMENTS: ______________________

____

4. Which of the following two codes would you prefer to represent a stall warning (the present mode is tone) ?

(a) Tone
(b) Voice

COMMENTS: ______________________

____

5. If a stall voice warning were installed in the aircraft, which of the following messages would you consider to be the most appropriate?

(a) Stall

(b) Recover

COMMENTS: ______________________________

____

APPENDIX B

SUBJECTIVE COMMENTS

PHASE I -- SURVEY

A) The following comments are relevant to the GCAS warning:

1. Crew may know they are temporarily going below GCAS warning. A non directive message warning the crew without giving a directive that the crew does not need.

2. Climb is another suggestion for a GCAS warning.

3. If the pilot is disoriented, PULL-UP is a good message. If the pilot is not disoriented, then he should know why he is getting the warning.

4. The volume of the GCAS warning should be directly proportional to the severity of the pull up required.

5. The appropriate message should be dependent on how far you are from impact.

6. PULL-UP, in the heat of the battle, could be interpreted as Pull Back.

7. "ROCKS" is another message for a GCAS warning.

B) The following comments are relevant to the SCP violation warning.

1. The voice warning is not necessary.

2. Should be fairly high pitched voice.

3. Low Altitude/Pull-Up.

C) The following comments are relevant to the AOA/SS caution.

1. Alpha-SIS is easier to recognize.

2. Use two different messages. "AOA" for alpha, and "Side Slip" for SIS.

3. Looks like too many things setting off the same caution. It's giving the pilot little useful information.

4. The caution is considered unnecessary.

5 We have sufficient lights for heater problems.

6. SIS would be best.

7. Malfunction light is good enough.

8. Tone is better than voice actuator.

D) The following comments are relevant to the Auto Pilot failure caution.

1. Not necessary except for ATF, and the message should be AUTO TF.

2. The only good caution would be an "RNE" (Reference Not Engaged) light.

3. We really don't need a voice message for autopilot.

4. Another message would be: "Modes deselected--Autopilot failed."

E) The following comments are relevant to the prioritization issue.

1. GCAS and SCP violation are equal priorities, depending on whether the aircraft is in ATF or manual mode.

2. The cautions are not needed.

F) The following comments are relevant to the warning mode preference.

1. In the F-111 A/E, light is more effective than tone.

2. Flashing red in a centrally located position is best indicator.

3. A combination is better since it affects more physical senses.

4. Depends on conditions.

5. Hard to judge, no previous experienced with voice.

6. Tone-light or voice-light combinations.

7. Depends on situation: In a high noise environment, light would provide more information. However, in a high

illumination condition, one more light may not be significant.

8. Already too many lights in the FB-111.

9. We already have too many tones, lights depends on location.

G) The following comments are relevant to the gender mode preference.

1. A female voice is more out of the ordinary in the fighter environment.

2. A female voice is distinguishable from other crew members.

3. Neither male nor female is best.

H) The following comments are relevant to the Stall warning mode preference.

1. Already used to tone.

2. Tone only. Pilots use the tone to check their turn performance. Do not distract with a voice.

3. The plane isn't stalling at Stall warning, so voice is irrelevant.

4. Don't fix it. It ain't broke.

5. The cockpit is already very noisy. Adding another voice may be counterproductive.

6. Suggests a two second tone, followed by a voice message.

7. Do not remove present tone. Add voice in addition.

8. Too many tones. I like voice.

I) The following comments are relevant to the Stall message preference.

1. I prefer "UNLOAD."

2. Neither Recover nor Stall. You are bleeding energy at high speed, so if anything, it should be "Energy."

3. I prefer "Alpha."

4. Would prefer both: Stall--Recover.

PHASE II -- SIMULATOR

A) The following comments are relevant to the GCAS warning.

1. "CLIMB" tells exactly what to do, and is more immediate.

2. "CLIMB" is more concise than "PULL-UP."

3. "CLIMB" is simpler; "PULL-UP" implies an abrupt pitch change which might place the aircraft outside flight parameters.

4. "PULL-UP" is same as civilian systems - proper sense

of urgency.

5. Prefer "PULL-UP" because I feel a pilot with alot on his mind may only key on the word "UP." I feel as I was working in the simulator - my mind working - "UP" was the word I heard. "CLIMB" does not stress the need for immediate reaction.

6. "CLIMB" was too benign; did not grab my attention or convey sense of urgency that "PULL-UP" did.

B) The following comments are relevant to the SCP violation warning.

1. "TF-Low" brings my attention to the LARA which I feel is most important. "ALTITUDE" made me simply pull on the stick much like a "CLIMB" command.

2. "TF-Low" relates the problem directly to the TFR system as opposed to "ALTITUDE" which could mean a number of things from altimeter problems to TFR problems.

3. "ALTITUDE" is too ambiguous and easily confused with GCAS. Another message could be "VIOLATION."

4. "TF-Low" immediately said to me "get away from the ground." When I heard "ALTITUDE" I looked at my altitude and wondered what was the deal with it.

5. "ALTITUDE" usually associated with medium altitude ATC clearance. "TF-Low" associated with death.

C) The following comments are relevant to the AOA/SS caution.

1. "ALPHA-SIDE-SLIP" is more indicative of the true problem.

2. Although "ALPHA" is more concise than "ALPHA-SIDE-SLIP," "ALPHA-SIDE-SLIP" relates directly to an alpha probe failure as opposed to alpha which could mean the AOA tape failed or my angle-of-attack was too high.

3. Of all the conditions that may cause an AOA/SS caution to be activated, only one (large initial sideslip or flight control disconnect with flaps up) reflects sideslip situation. All others are alpha related, indicating a significant hazard, and generally could not be pilot induced as a large initial sideslip might be. My feeling is the "ALPHA" phrase is more acceptable.

4. A toss up.

5. Preferred single word warning. Here - no preference.

D) The following comments are relevant to the Autopilot failure caution.

1. "AUTOPILOT" brings attention immediately to the Autopilot.

2. "AUTOPILOT" is more concise.

3. Single word, "AUTOPILOT," reflects the situation well and is less distracting.

4. The longer (3-5) syllable unique commands are better and more easily recognized in the presence of radio chatter and crew communication.

5. Preferred a response telling me it failed; not just to check the switches.

E) The following comments are relevant to the redundancy issue for GCAS.

1. I would like to see a separate light - a warning light much like the Radar Alt Low.

2. Any redundant warning system that keeps the pilot from hitting the ground is very useful.

3. Voice should be more than enough.

4. GCAS can easily fail. Radar Alt Low warning lamp needs to be present as a backup and should be restored to full size. It's a simple system backup to an important warning.

5. I often notice lamp before voice.

6. I would like to see a visual cue on the HUD (D model). During bombing operations, you're always staring out-the-window.

7. Any heads-down light would be worthless. Fly-up bars on the HUD would be useful.

8. Recommend to flash LARA (or CARA) light simultaneously due to the importance of the warning.

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